

A High Performance Image Data Compression Technique for Space Applications

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Abstract- A highly performing image data compression technique is currently being developed for space science applications under the requirement of high-speed and pushbroom scanning. The technique is also applicable to frame based imaging data. The algorithm combines a two-dimensional transform with a bit-plane encoding; this results in an embedded bit string with exact desirable compression rate specified by the user. The compression scheme performs well on a suite of test images acquired from spacecraft instruments. It can also be applied to three-dimensional data cube resulting from hyper-spectral imaging instrument. Flight qualifiable hardware implementations are in development. The implementation is being designed to compress data in excess of 20 Msamples/sec and support quantization from 2 to 16 bits. This paper presents the algorithm, its applications and status of development.

I. INTRODUCTION

Advances in sensor and detector technology have ushered in a new era of scientific instruments for space applications. Future remote sensing platforms will combine unprecedented spatial and signal resolutions or, in addition, offer multi-spectral capabilities. The result is a surge of the data volume that has to be collected, buffered, transported, and archived in the space-to-ground data system.

To alleviate the burden due to the extra data volume, data compression has been suggested as one of the option to help transport/archive data. Reference [1] provides a growing list of over twenty missions that have utilized the lossless data compression recommended by the Consultative Committee for Space Data Systems (CCSDS). However, the amount of data reduction achievable with lossless data compression is usually limited by the inherent entropy measurement in the data, and for many remote sensing applications it is limited to about two-to-one on average.

For other applications that require higher data reduction, as in quick-look or direct-broadcast of sensor data, a technique with tunable compression rate is desirable. There exist various algorithms that provide good data reconstruction performance at high data reduction, most notably the International Organization for Standards (ISO) JPEG2000 [2]; however, none has adequately addressed the implementation requirement arising from push-broom instruments for space applications.

This paper gives a summary of a technology development effort which takes into consideration for high-speed, low-power requirement for space implementation.

A. Requirement for Space Applications

In 1998, CCSDS compression sub-panel established a set of eight requirements listed in Table 1. These requirements help to focus our effort in devising algorithms for space applications.

TABLE 1
CCSDS REQUIREMENTS FOR IMAGE DATA COMPRESSION

Offer royalty free license to all CCSDS space agencies if any patent is included in the algorithm	O
Process both frame and non-frame (push-broom) data	M
Offer adjustable coded data rate or image quality (up to a lossless mode)	M
Work over large quantization range (4 to 16-bit input pixels)	M
Offer real-time processing with space qualified electronics (over 20 Msamples/sec, less than 1 watt/Msamples/sec)	M
Provide progressive transmission (either resolution or PSNR progressive)	O
Require minimum ground operation	M
Allow for error containment within a small image area, in case of an uncorrected channel error	M

M: mandatory, O: optional

The real-time processing requirement in item 5 is based on year 2000 available radiation tolerant circuit fabrication technology. As space science technology advances with time, the quoted processing speed and power consumption need to be adjusted.

B. Architecture of The Compression Scheme

An architecture for our 2D compression scheme is given in Fig. 1. The compression begins with buffering input data for a few lines before a de-correlation stage. The de-correlated data are organized into 8x8 blocks and further processed by a bit-plane-encoder (BPE) with external RAM element. The de-correlator can be any transform that produces 8x8 frequency blocks, thus allowing a wide range of selection including: lapped transform (LT) [3], discrete cosine transform (DCT) [4], or a locally computed discrete wavelet transform (DWT) [5].

The approach requires no application-specific look-up table to optimize its performance and is error-resilient in that error propagation is contained within known numbers of scan lines for push-broom applications, depending on the transform employed.

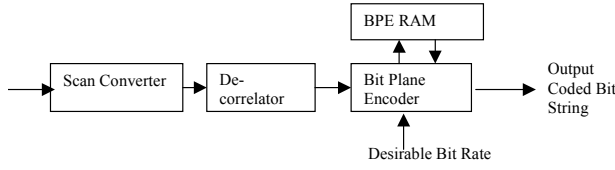


Fig. 1 Architecture of the Compression Scheme

II. THE BIT PLANE ENCODER

The bit plane encoder takes as input the 8×8 transform domain components and further groups them into three family trees, each has one parent, four children and sixteen grand children as shown in Fig. 2. The magnitudes of components are scanned for any most significant bit (MSB) on the scanned bit plane. This bit plane scanning proceeds from the top most bit plane downward, thus inherently accomplishes a quantization of transform coefficients by a factor of 2 in succession. The positional information of those identified components is represented by this family tree structure and may be further coded for efficiency. This information along with their sign information are shifted to the output bit string from higher bit planes to lower bit planes.

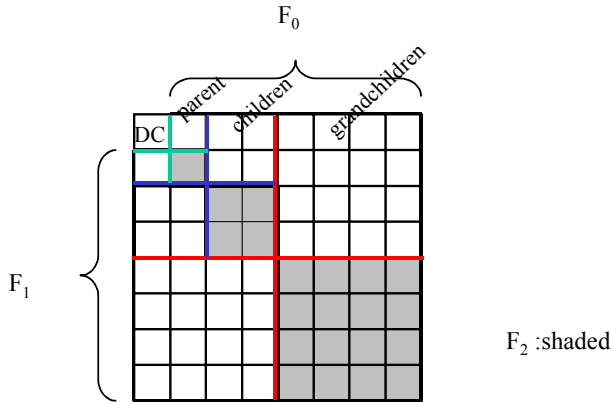


Fig. 2 Organization of 8×8 Coefficients

Uniform compression performance over a strip of input data is obtained by processing the same bit plane for all the blocks in a strip of input data to the de-correlator. Fig. 3 shows how data from each bit plane are organized and metered out to provide exact compression rate desired by the application. On each bit plane, each pattern class (parent, child or grand child) is processed across all the blocks before progressing to the next pattern class, thus providing sub-bit plane accuracy at user specified compression rate.

Transformed Coefficients in Bit Planes:

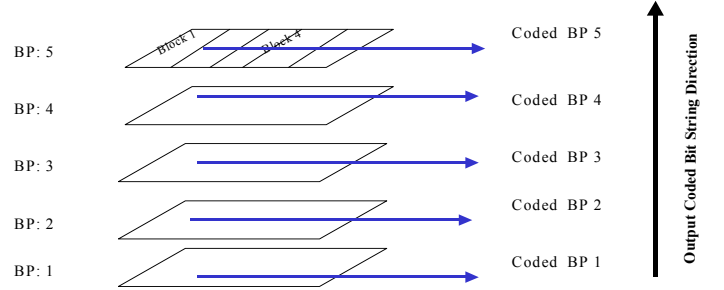


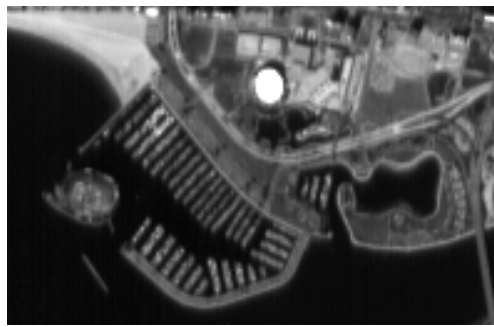
Fig. 3 Flow of Coded Data from Bit Planes (BP)

III. PERFORMANCE

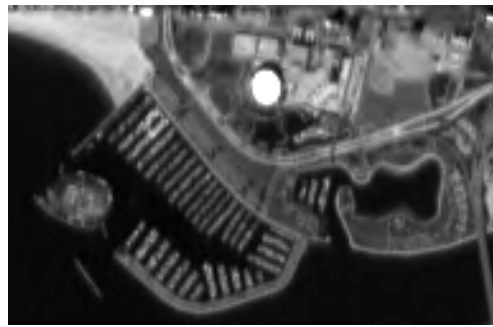
In the April 2003 CCSDS meeting, a 2D data compression scheme consisting of a wavelet transform and the BPE has been selected as recommendation for future space applications. The wavelet transform uses the same floating-point 9/7 wavelet as in JPEG2000. Additional study is undergoing to evaluate the integer 9/7 wavelet transform for possible inclusion in the recommendation. The combination of an integer wavelet with the BPE will provide tunable compression from lossless to any desirable compression ratio, as long as the quality of the lossy decompression does not compromise science.

Both qualitative and quantitative evaluation has been performed on the set of twenty-one CCSDS test images ranging from 8-bit to 16-bit and from different types of sensors with varying resolutions. Reference [1] compares the DWT+BPE scheme in push-broom mode with the JPEG2000 scan-based mode, both coders show comparable performance in quantitative measurement.

Qualitative evaluation is usually rather subjective. At low compression ratio, or equivalently higher bits-per-pixel (bpp), it is difficult to differentiate decompressed data from different techniques. At low bpp, the effect becomes pronounced. Such is the case shown in Figs. 4-7 on sub-images cropped from the decompressed SPOT-panchromatic test image. For these high resolution images, compression ratio at over 10:1 is usually not acceptable even to novice data users.



Original



CCSDS

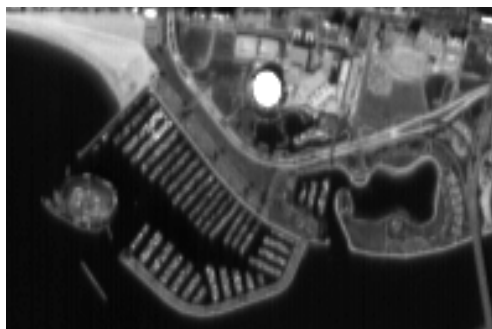


JPEG



JPEG2000

Fig. 4 Visual Evaluation at 1 bpp (compression ratio= 8)



Original



CCSDS



JPEG



JPEG2000

Fig. 5 Visual Evaluation at 1 bpp (compression ratio= 16)



Original



CCSDS



JPEG



JPEG2000

Fig. 6 Visual Evaluation at 1 bpp (Compression Ratio = 8)



Original



CCSDS



JPEG



JPEG2000

Fig. 7 Visual Evaluation at 0.5 bpp (Compression Ratio = 16)

The DWT+BPE scheme can be applied to other types of data. One example is the hyper-spectral data cube. The spectral domain often has high correlation among spectral channels. Applying the current 2D compression technique to the spectral-spatial domain of the data cube provides more effective de-correlation of data and could achieve more data reduction than applying the technique in the spatial-spatial domain if the spatial resolution is good. Study utilizing this method is underway for the future Hyperspectral Environmental Suite (HES) sounder instrument on the GOES-R mission.

IV. TECHNOLOGY STATUS

An application specific integrated circuit (ASIC) for executing the BPE algorithm is currently under design utilizing radiation tolerant (RT) design methodology. The chip is expected to process over 20 Msamples/sec at lower than 0.15 watts/Msamples/sec. The throughput rate is limited by currently available rad-hard RAM chip that would serve as the external RAM for the BPE processing. The design is expected to be completed by the end of 2003. Fabrication is expected in 2004.

The BPE algorithm, together with DWT, has been selected by the CCSDS compression panel as recommendation for image data compression. Several independent groups will be developing verification software for users. The CCSDS recommendation will be issued in mid-2004.

Plans have been made to develop a RT DWT ASIC in 2004/2005 at over 20 Msamples/sec. With the completion of the DWT chip, a space qualifiable compression module can be implemented for NASA's missions.

REFERENCES

- [1] P.-S. Yeh, G. Moury and P. Armbruster "The CCSDS Data Compression Recommendations: Development and Status," *Proc. SPIE Applications of Digital Image Processing*, July 7-10, 2002, Seattle, WA
- [2] JPEG2000, www.jpeg.org
- [3] Henrique S. Malvar, *Signal Processing with Lapped Transforms*, Artech House, 1992.
- [4] K. R. Rao and P. Yip, *Discrete Cosine Transform: Algorithms, Advantages, Applications*, New York: Academic Press, 1990
- [5] B. Masschelein, J. G. Bormans and G. Lafruit, "Local wavelet transform: a cost-efficient custom processor for space image compression", *Proc. SPIE Applications of Digital Image Processing*, July 7-10, 2002, Seattle, WA